Visiting Faculty Research Program

2015 Research Topics

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Autonomy, C2, and Decision Support

Enabling Robust Autonomy

Steven Loscalzo

Autonomy has been identified in the Air Force Technology Horizons report as one of the key technologies needed to support the USAF over the next 20 years. Many research challenges must be addressed before autonomous systems can be reliably deployed in practice, and AFRL/RI is broadly interested in addressing those challenges related to the need to process massive amounts of sensed data to make informed decisions. Big Data problems can occur in autonomous systems as a result of being informed by many sensors, communicating between many autonomous agents, or by attempting to leverage previously gathered information to better adapt to future situations, as well as from a variety of other causes. Generally, AFRL/RI is interested in topics from the knowledge discovery from data and machine learning fields that can help autonomous agents make reliable and correct decisions in real-world scenarios. Specific topics include:

Efficient representation discovery –In many cases, the raw sensory inputs that provide a system's observations of the environment are not ideal for learning algorithms. In many cases, they provide more information than necessary to achieve a particular task, and may report data at too fine a granularity to efficiently work with directly. We are interested in pursuing novel approaches that automatically discover representations where tasks can be accomplished more efficiently than in the raw input space or spaces found by current automatic techniques. Such tasks may be derived from any area of machine learning, such as supervised, unsupervised or reinforcement learning. Possible solution concepts may be based in the areas of deep learning, feature selection, or hierarchical state space decomposition.

- Anticipating versus Reacting - Conditions in real-world environments are dynamic - threats emerge and may be neutralized, opportunities appear without warning, etc. - and robust autonomous agents must be able to act appropriately despite these changing conditions. To this end, we are interested in identifying events which signal that a change must be made in one agent's behavior by mining past data from a variety of sources, such as its own history, messages from other autonomous agents, or other environmental sensors. This capability would allow agents to learn to anticipate and plan for scenario altering events rather than reacting to them after they have already occurred.

Course of Action Modeling and Simulating

Shelby Barrett

Military command and control systems are complex systems of systems that combine numerous applications programs and cross multiple networks, computing systems, and databases. As the Air Force moves toward integrating command and control functions into an integrated command and control system, evaluation of courses of action must be able to handle multiple and diverse modeling and simulation tools and approaches. New means are needed to support enhanced event monitoring and task execution, situational assessment, automated decision aids for better course of action analysis and selection, dynamic resource management, and agile C2 enterprise management with the goal of allowing more adaptable, real-time, resilient operations. Of principal concern are the discovery, development, and generation of near real-time Courses of Action (COAs) through modeling and/or simulation techniques which may be utilized to rapidly adapt to, or avoid, changes to the unique military operational environment. Research areas of interest within this topic include:

- Ability to continuously analyze the current world state and its effect on the C2 capabilities of the Air Force.
- Any developed framework will be used to assess, predict and react to changes in a situation by predicting possible futures and recommending optimal options and provide a ranked, composite score to assist human planners in deciding which courses of action (COAs) to recommend to the commander.
- Machine to machine population of model parameters
- Ability to efficiently include external, third-party techniques, models, information products, or knowledge is highly desired.
- Methods for developing enterprise models of integrated command and control systems that may include new and legacy components.
- Development of integrated command and control system measures of performance and measures of effectiveness (MOPs/MOEs) that can then be evaluated via simulation.
- Methods for rapidly developing simulation scenarios for exercising command and control system models.

Context Sensitive Information Visualization to Enhance Situational Awareness

Jason Moore

Situational awareness is the "fabric" for collaboration and team synchronization in military operations. To be most enabling, its content and the presentation of that content must adapt to the information needs of individual team members, their tasks, and their current situation (context).

It must seamlessly bridge the strategic, operational and tactical levels of military operations supporting decisions and actions at all levels. We are looking for researchers to explore the science of adaptive, context sensitive visualization of complex data rich environments, to support team self-synchronization/situation awareness and develop the underlying science needed to engineer future military systems.

Research areas of interest within this topic include:

- Visualization of complex information systems.
- Various techniques for de-cluttering data and the visualization of that de-cluttered data.
- Appropriate visualization abstractions that work over WebGL/Javascript or other browser enabled capabilities and languages
- Composable visualization system interfaces that reduce the amount of user end programming, but still offer rich expressivity
- Course of Action determination visualization system that presents the facets of information and the way the system derived the set and ranking of COAs

Advanced Information Visualization and Human Computer Interaction

Peter Jedrysik

In order to provide airmen with an information environment that is dynamic and tailorable based on information needs, we are developing advanced visualizations techniques and interactive displays. Some of our technical challenges include fast access to voluminous dynamic data; high fidelity representations; effective visual interfaces for analyzing large data sets; evaluation metrics for visualization success; effective interaction techniques; integrating large high-resolution displays into a seamless computing environment; and perceptually valid ways of presenting information on a large display. Researchers will investigate effective use of visualization hardware and software. Specific domains include: man machine models; large screen and handheld multi-touch displays; multi-modal interaction; continuous speech; natural language dialogue; eye tracking and gesture interpretation; intelligent interfaces and adaptive mediators; untethered pointing and interaction devices; 3D graphics and visualization; synthetic environments and virtual world C2 applications; display tiling and high resolution media; collaborative interaction and decision making; integrated C2 situational awareness across air, space, and cyber domains; and mission planning and rehearsal.

Challenges in Massive Point Cloud Visualization and Analysis

Aaron McVay

Historical LiDAR collection efforts have already generated massive point cloud datasets, and new efforts are collecting as much as 1 Terabyte of data per hour of flight. Currently available applications/toolkits for processing point cloud data have several limitations which prohibit scalability, timely dissemination and analysis. The focus of this research is on techniques that could be used on raw data during collection (or very soon after), enabling clients to gain access in near real-time to data for analysis or to improve situation awareness. Research efforts include the design of server based techniques to minimize client systems processing and storage requirements, and development of visualization capabilities usable by client applications. Research areas of interest include:

- Visualization of point cloud data using level of detail, or decluttering algorithms
- Techniques for fusion of supplementary geospatial data sources with point cloud data
- Techniques for classifying 3D geometric patterns within point cloud data
- Methods for point cloud change detection
- Automation techniques to assist in 3D model generation from point cloud data

Mission Driven Enterprise to Tactical Information Sharing

James Milligan

Forward deployed sensors, communication, and processing resources increase footprint, segregate data, decrease agility, slow the speed of command, and hamper synchronized operations. Required is the capability to dynamically discover information assets and utilize them to disseminate information across globally distributed federations of consumers spread across both forward-deployed tactical data links and backbone enterprise networks. The challenges of securely discovering, connecting to, and coordinating interactions between federation members and transient information assets resident on intermittent, low bandwidth networks need to be addressed. Mission prioritized information sharing over large-scale, distributed, heterogeneous networks for shared situational awareness is non-trivial. The problem space requires investigation, potential solutions and technologies need to be identified, and technical approaches need to be articulated which will lead to capabilities that enable forward deployed personnel to reach back to enterprise information assets, and allow rear deployed operators the reciprocal opportunity to reach forward to tactical assets that can address their information needs.

Visual Computing to Augment Perception

Richard Fedors

The massive data flows generated by increasingly ubiquitous sensors, network communications, various data bases, and other sources can quickly overwhelm the available processing capabilities used to make that output understandable to a human operator. Decision makers across all levels face this challenge - seeking better tools to accurately perceive the environment, recognizing impending events, and quickly formulating response plans. Visual computing offers the potential for innovative solutions; by converting vast data and numerical computations into imagery which can be processed quickly by highly parallel 'preconscious' visual channels in the brain. This could achieve "a fusion between machine computation and thinking" to increase the commanders' situational awareness and decision speed for controlling dynamic operations. Expected research will combine advances in several fields of knowledge including cognitive science, machine learning, visualization, and decision science. Potential development could include multi-faceted representations for complex physical/virtual environments which are attuned to innate human perceptual abilities. Such technology has the potential for enabling a new generation of flexible, resilient command and control capabilities.

Decentralized Planning for Command and Control

Kurt Lachevet

In an effort to support the Air Force's mission to develop robust autonomous Command and Control (C2) systems in contested environments, we are interested in furthering the identification of problems, and development of solutions, in decentralized planning for C2. We are interested in planning solutions in resource-constrained environments (processing power, data, and communication restrictions) with time-sensitive goals. The following topic areas are of interest as we seek to provide a decentralized C2, collaborative planning capability to enable continued execution of plans in a contested environment.

- Mixed-Initiative Plan Adaptation – When communications with a centralized planning authority are compromised, the challenge becomes the continuity of operations at decentralized locations can become difficult. Capabilities of interest include effective methods of plan adaptation that don't require a complete re-planning phase in a centralized planning environment, and mixed-initiative plan adaptation solutions in a resource-constrained environment.
- Plan Deconfliction – As plans are successfully adapted to ensure mission continuity, how is re-synchronization effected when communications between distributed/decentralized C2 components are lost or compromised, and then restored – if at all. Local planning by distributed agents may be locally effective, but often leads to the need for later plan deconfliction and negotiation once communications resume and partial plans and plan fragments are aggregated. Finding effective ways to reduce the occurrence of initial plan conflicts as well as to minimize the amount of time required to de-conflict a set of partial plans is critical to time sensitive mission requirements. We are interested in plan de-

confliction and synchronization solutions enabling inter-plan collaboration, efficient deconfliction, and plan (re)synchronization for autonomous/decentralized C2.

Network Defense through Dynamic Attack Surfaces

David C. Last

Today, information system defenders face an asymmetric disadvantage against attackers. Current information system defenses (at the network, host machine, and lower levels) are static, keeping the same configuration over time with little or no change. Consequently, attackers may perform reconnaissance at their own leisure and launch attacks when they are ready. In response to this situation, a new class of defenses has been developed, called Moving Target Defenses (MTDs). MTDs dynamically change the configuration of defenses and/or target machines over time, thus shortening the reconnaissance/plan/attack cycle available to the adversary. MTDs come in many forms, such as at the network level (e.g. IP-hopping, port-hopping), host machine level (e.g. OS hopping using multiple VMs to host a web service), and lower levels (e.g. Address Space Randomization, Instruction Set Randomization).

Although a fair amount of work has been done to develop MTDs, little work has been done to study the effects or optimal deployment of MTDs. This research seeks to develop the science of MTD effect analysis for the optimal deployment of MTDs in relation to the resource and security requirements of the set of missions currently operating on the information system. Possible areas of research include MTD characterization (to quantify the security provided and resources consumed by a given MTD), mission mapping (to determine the resource and security requirements of an active cyber mission), or optimal MTD deployment with a focus on preventing cyber friendly fire (MTDs interfering with each other or any of the active cyber missions).

Connectivity and Dissemination

Wireless Optical Communications

David Hughes

John Malowicki

Quantum communications research involves theoretical and experimental work from diverse fields such as physics, electrical and computer science and engineering, and from pure and applied mathematics. Objectives include investigations into integrating quantum data encryption with a QKD protocol, such as BB84, and characterizing its performance over a roughly 30 km free space stationary link.

Free Space Optical Communication Links: Laser beams propagating through the atmosphere are affected by turbulence. The resulting wave front distortions lead to performance degradation in the form of reduced signal power and increased bit-error-rates (BER), even in short links. Objectives include the development of the relationship between expected system performance and specific factors responsible for wave front distortions, which are typically linked to some weather variables, such as the air temperature, pressure, wind speed, etc.

Keywords applicable to these studies are: quantum cryptography, free space laser propagation, Coherent state quantum data encryption, laser beam propagation through turbulent media, integration of quantum communications system with pointing, acquisition, and control system.

Airborne Networking and Communications Links

John Matyjas

Michael Medley

This research effort focuses on the examination of enabling techniques supporting potential and future highly mobile Airborne Networking and Communications Link capabilities and high-data-rate requirements as well as the exploration of research challenges therein. Special consideration will be given to topics that address the potential impact of cross-layer design and optimization among the physical, data link, and networking layers, to support heterogeneous information flows and differentiated quality of service over wireless networks including, but not limited to:

- Physical and MAC layer design considerations for efficient networking of airborne, terrestrial, and space platforms;
- Methods by which nodes will communicate across dynamic heterogeneous sub-networks with rapidly changing topologies and signaling environments, e.g., friendly/hostile links/nodes entering/leaving the grid;
- Techniques to optimize the use of limited physical resources under rigorous Quality of Service

- (QoS) and data prioritization constraints;
- Mechanisms to handle the security and information assurance problems associated with using new high-bandwidth, high-quality, communications links; and
- Antenna designs and advanced coding for improved performance on airborne platforms.

Cognitive RF Spectrum Mutability

John Matyjas

Michael Gudaitis

When considering operations across terrestrial, aerial, and space domains, effective use of the limited Electromagnetic Spectrum (EMS) for a multitude of purposes is critical. The combined pressures of increasing demand for services and less available bandwidth for all make it imperative to develop capabilities for more integrated, flexible and efficient use of available spectrum for all functions (communications, radar, sensors, electronic warfare, etc.) across all domains (terrestrial, aerial, and space). In recognition of the need for affordable, multi-functional software-defined radios with spectrum agility and survivability in contested environments, this research effort seeks lightweight Next-Generation Software Defined Radio (SDR++) architectures and advanced waveform components for affordable solutions based on COTS and non-development items (NDI), relevant operational security, and appropriate trades in levels of software & hardware roots-of-trust. This will create an innovative high-performance flexible radio platform developed to explore the use of next-gen cognitive, smart-radio concepts for advanced connectivity needs across heterogeneous waveform standards and multiple EMS use-cases; while meeting tighter cost budgets and shorter time-to-fielding. The technology developments will support global connectivity and interoperability via multi-frequency/band/waveform reprogrammable radios for networked, multi-node aerial layer connectivity & spectrum mutability, providing system composability and engineered resilience.

Next-generation Aerial Directional Data Link & Networking (NADDLN)

John Matyjas

Nathaniel Rowe

Given the scarcity of spectrum, there is a desire to develop self-forming, self-managing directional tactical data links operating at higher frequencies. Directional networking provides an opportunity to increase spectral efficiency, support ad-hoc aerial connectivity, improve resistance to intended/unintended interference, and increase the potential capacity of the link. However, complexity is added to the pointing, acquisition and tracking (PAT) required to establish and maintain a network of directional links over omnidirectional systems. Research interests reside in (1) the ability to make real-time content/context-aware trades involving capacity, latency, and interference tolerance; (2) mission-aware link and network topology control; and (3) affordable

apertures and PAT systems; ultimately, to deliver new capabilities for next-generation aerial directional data link & networking (NADDLN).

Hybrid Multi-User Detection for Random Access in Tactical Airborne Networks

Michael Gudaitis

Thomas Scatko

Existing access techniques in wireless systems are inefficient for large numbers of geographically spaced mobile users. Standard access techniques such Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), or Carrier Sense Multiple Access (CSMA) have limitations that reduce the effective utilization of the wireless data channels. Hybrid Multi-User Detection (MUD) techniques may allow ad-hoc users to randomly access the channels across space/time/code/frequency and receive/detect and receive and detect multiple users through advanced detection and feedback loops in the receiver signal processing. These techniques need to be explored and developed further to evaluate the applicability and effectiveness in tactical airborne networks.

Elastic Networking for the Aerial Layer

Michael Hartnett

John Matyjas

The characteristics of today's aerial layer networks are limiting effective information sharing and distributed command & control (C2), especially in contested, degraded, operationally limited (CDO) and anti-access area denial (A2/AD) environments, where the lack of interoperability and pre-planned/static link configurations pose the greatest challenges. Advanced research in wireless networking is sought to support aerial information exchange capabilities in highly dynamic environments. This includes but is not limited to: disruption/delay tolerant networking; radio-to-router interface protocols; opportunistic transport protocols; resilient data/message on-demand prioritization; dynamic performance enhancing proxies; and mesh networking.

Software Defined Networking

Michael Hartnett

John Matyjas

Software Defined Networking (SDN) is a recent trend in computer networking with strong vendor support that allows a software program to control the behavior of an entire network. SDN separates a network's control logic from the underlying data forwarding plane, which allows network operators to write high-level multi-mission policies and define complex tasks to dynamically control network and its resources to meet on-demand in-theater mission requirements while mitigating vulnerabilities and threats in cyber and Electro Magnetic (EM) domains.

High level network control makes it possible for operators to specify more complex tasks that involve integrating many disjoint network functions (e.g., security, resource management, and prioritization, etc.) into a single control framework, which enables (1) mapping mission/application level requirements to a set of tangible network configurations, (2) robust and agile network reconfiguration and recovery, (3) extremely flexible network management and planning, and, in turn, (4) dramatic improvements in network efficiency, controllability, and survivability. The topic seeks highly motivated research on how SDN can support dynamic, resilient local and global C2 for joint tactical edge network (JTEN) operations.

Situational Awareness and Resiliency in Cross Domain Security Systems

Michael Mayhew

Cross-domain guard systems are a key component within any cross domain information sharing capability. Due to the guard’s gatekeeper role between domains, it is a primary target for cyber attack from a low-side network trying to gain high-side access, or malware on the high-side trying to exfiltrate data to the low-side. Historically these systems have been designed as standalone units connecting the various security domains, but with separate management and reporting channels. They have little visibility of the status of their connected networks and the connected networks have little visibility on the status of them. Resiliency is an important trend in designing systems with regard to cyber defense. Simply put, resilience is the ability to provide and maintain an acceptable level of service in the face of faults and challenges to normal operation. Resilience is related to survivability, which builds on the disciplines of security, fault tolerance, safety, reliability, and performance. The approach assumes systems will be compromised to some extent and implements design strategies and techniques that support a balanced combination of protections, detections, and adaptive technical and operational responses that dynamically evolve in response to current and future cyber events. One important aspect of achieving resilient systems is to have good situational awareness of the environment and adapt to changes within that environment. This topic aims to view a cross-domain guard system as a key part of designing a resilient Multi-Level Security (MLS) system. Formalize techniques for collecting situational awareness information for the various connected security domains, sharing this information securely, and acting on this information based on policy in a

specific guard implementation agnostic fashion. Research should examine the current state-of-the-art of malware sensing and reporting in a closed systems environment, guard status reporting, guard management infrastructures, and applicable resiliency techniques (Protect/Deter, Detect/Monitor, etc.). The expected outcome of this effort is a new guard architecture, or an extension to an existing guard architecture where the guard is capable of acquiring sensor information from the various security domains that it is connected to, and increasing / decreasing its security posture appropriately based upon what it can detect.

Mobile Android Multi-Biometric Acquisition

Michael Mayhew

In order to minimize costs, increase accessibility of information and lessen the equipment burden on operators, several entities within the military, federal and municipal levels of government are finding it necessary to increase the functionality of their mobile devices. The Security-Enhanced Android operating system (SE-Android) has become the mobile OS of choice for secure cellular communications. Also, because information needs to be shared with various entities, security of those devices, especially those using ARM-based processors, has become paramount. It is crucial that all available sensors on these devices be leveraged not only to identify the legitimate user, but also to gather as many biometric attributes as possible for analysis of target attributes, and mission execution. Mobile and tactical cross-domain devices such as phones and tablets can use their myriad of sensors produce numerous data sets (imagery, audio, location, etc.) which may be useful in a number of scenarios. One such scenario is properly exploiting these data sets to provide a rich set of biometric data for authentication back to the device owner. While fingerprint, iris/retinal, voice, etc. and voice authentication is emerging, there are many others that warrant additional investigation and research. Such capabilities include: Near Field Communications (NFC), RFID, human biometrics (pulse, heart-rate, blood pressure), and gait. On the military side, these advanced capabilities add a second form factor authentication capability that would not require the use of fingers, voice, eye scans, or long passwords that are currently being deployed today. Matching the phone to the biometrics of the user (such as heart rate, pulse, blood pressure, etc.) adds a second form factor for our troops that do not have the ability to authenticate without jeopardizing their mission. Mapping a person’s biometrics into the device, uniquely matches the device to the owner and when such readings change, the device should lock and only then rely on other form factors as proof of the owner's. Researching and demonstrating the benefits of advanced biometric attributes to assure identity of the operator in realistic environments (smoke, noise, dirt, stress, etc.) may add non-trivial benefits to the security and trustworthy utilization of these devices. Other factors to consider during this research are battery usage, potential privacy concerns, reducing or (ideally eliminating) any external devices, and accuracy of various biometric authentication capabilities when implemented through these commercially available phones and/or tablets.

Secure Tactical Remote Executable Application Monitor

Michael Mayhew

Mobile and tactical cross-domain application functionality and communication is limited by the lack of persistent and reliable network connections in the field. Devices such as phones, tablets, and their related sensors produce various data sets (imagery, SIGINT, GPS, etc.) which should be shared and analyzed regardless of the quality and reliability of the backbone network connection. These devices need to function correctly for the warfighter in clandestine and rugged environments, without the need for constant reliable network connections. This is an inherent weakness of cloud technology as it stands, especially when critical mobile applications are based in the cloud. While some technologies are being built to interface GOTS devices physically with existing networks, more development needs to be done. As such, research should be undertaken to enable these mobile devices (phones, tablets, etc) to recognize and operate on any available network in real time while reacting appropriately to the degree of connectivity these networks make available without excessively impacting the performance of commercial and GOTS applications. The scope of the research includes DIL (Disrupted, Intermittent, Latent) network conditions existing for periods of seconds to weeks with minimal impact to the operator. The ultimate goal would be to allow mobile devices to consistently operate regardless of their physical and networking environments. Note that this includes potentially utilizing more than one concurrent connection across multiple levels of classification and/or degrees of trust. This may require sending data at lower levels of classification over higher-level networks or vice versa, and may well induce different levels of sensitivity and/or classification of various sensors available to the device.

Reactive Service Migration

James Milligan

Reactive service migration involves service fault detection and fail-over mechanisms, information service workload migration strategies to relieve overloaded network resources, and pre-positioning of information and services by recognizing the usage patterns of information consumers to anticipate their needs ahead of time. Reactive service migration fail-over mechanisms might make use of workflow compensation, service redundancy, or other exception handling techniques. Workload migration may involve the use of load balancing techniques to achieve optimal resource utilization, maximize throughput, minimize response time, and avoid overload. Pre-positioning of information and services might require the tracking and detection of events or changes in state which indicate an impending user need. In all cases, reactive service migration is concerned with optimizing the quality and availability of information management system services.

Enhanced Information Streaming

Ralph Kohler

Enhanced information steaming deals with techniques to annotate and otherwise characterize the content of steaming data in order to enrich our ability to interact with the data in ways that go beyond the frames and timelines that current video interfaces impose upon the user. Although frames and timelines are useful notions, they are less well suited for other types of interactions with video. In many cases, users are likely to be more interested such things as motion, action, character, and theme. For example, finding a moment in a video in which an object is in a particular place may be of interest, or the goal might be to compose a still image from multiple moments in a video. Although it is possible to compute object boundaries and to track object motion, typically this information is not captured in a manageable way, nor do present interfaces utilize this information for user interaction. Of interest are ways to embed glyphs and graphics into steaming media (such as descriptive labels, illustrative sketches, path arrows indicating motion, etc.), associating metadata with the indexed content of streaming data, and making this additional information available to consumers for managing the playback and use of streaming information in ways that add value based on specific user needs.

Combinatorial Designs for Key Distribution

Victoria E. Horan

Key pre-distribution schemes are required for certain kinds of wireless networks. One approach is to utilize combinatorial design theory as a means of developing a set system of keys with a specified amount of overlap. These sets of keys are then deployed with the nodes in the wireless network. Thus the robustness and connectivity of the network depend solely on the key pre-distribution scheme employed. Combinatorial designs provide a method for addressing these concerns in a scalable manner.

Approximation Algorithms for NP-Hard Network Problems

Victoria E. Horan

Many network problems can be traced to NP-complete problems in combinatorics and graph theory. For example, coverage can be converted to a dominating set problem in graph theory. Certain structures can reduce the complexity of our problem and allow simple constructions of the desired outputs. However, approximation algorithms are essential to provide the base cases necessary to develop sound conjectures and theory. By developing more efficient algorithms and utilizing the power of parallel computing, we can more efficiently discover broad theoretical results. The following topics must be addressed: (1) underlying combinatorics or graph theory problem to be addressed, (2) network application of problem, and (3) areas of improvement under the current “best performers”.

Dynamic Resource Allocation in Airborne Networks

Elizabeth Bentley

From the Air Force perspective, a new research and development paradigm supporting dynamic airborne networking parameter selection is of paramount importance to the next-generation warfighter. Constraints related to platform velocity, rapidly-changing topologies, mission priorities, power, bandwidth, latency, security, and covertness must be considered. By developing a dynamically reconfigurable network communications fabric that allocates and manages communications system resources, airborne networks can better satisfy and assure multiple, often conflicting, mission-dependent design constraints. Special consideration will be given to topics that address cross-layer optimization methods that focus on improving the performance at the application layer (i.e. video or audio), spectral-aware and/or priority-aware routing and scheduling, and spectral utilization problems in cognitive networks.

Cyber Science and Technology

Cyber Defense Research

Warren Debany

Cyber Defense is concerned with the protection and preservation of critical information infrastructures in order to ensure the United States' dependency on cyberspace remains beneficial and does not turn a technological advantage into a vulnerability.

This technology area seeks to: 1) protect our own information space through assurance, agility, denial, deception, and deterrence; 2) enable our system to automatically survive attacks through an innate ability to deal with unanticipated states and environments; 3) provide the means to identify, understand, attribute and localize vulnerabilities before they are exploited, and attacks as they occur; and 4) recover and reconstitute systems, data, and information states rapidly to ensure continuity of operations.

Fundamental research areas of interest within this topic include:

- Methods for mission mapping and dependency analysis within complex systems; going beyond computer and network assurance to mission assurance.
- Design of trustable systems composed of both trusted and untrusted hardware and software; study of virtualization and trusted platforms
- Algorithms and innate mechanisms that enable systems to automatically continue correct operation when presented with unanticipated input or in the face of an undetected bug or vulnerability.
- Techniques that can disrupt an attack during its early stages (reconnaissance, planning, and testing), such as polymorphism, agility, and randomization, at all layers of networking and computer architectures, to reduce the attackers' understanding of our systems and their ability to launch attacks, while maintaining our own situation awareness: “moving target defenses.”
- The ability of information systems to “fight through” attacks, without operator intervention, in a contested environment characterized by “zero day” attacks.
- Examination of assumptions, mechanisms, and implementations of security features that may be adequate for wired networks and devices but provide opportunities for attacks on wireless and mobile systems.
- Theories of complex systems describing interactions of large systems and systems of systems that lead to better understanding of their emergent behaviors during attack and reconstitution; epidemiological models that may be used to predict system responses to Internet worms and coordinated attacks as well as analyses of self-healing and self-restoring systems.

Development of new cryptographic techniques is not of interest under this research opportunity.

Achieving Survivability in Cyberspace

Kevin Kwiat

We begin by noting that unlike air or space, cyberspace differs in a fundamental way: air and space are natural settings, but cyber is man-made. As a made-made entity, cyberspace is composed of networking and information resources – and is therefore subject to human control. Because of this distinction, the human ability to create and sustain cyber-level linkages can become a venue for malice.

Defense of cyberspace is challenging. The seemingly endless breadth of cyberspace coupled with the technological depth of its composition can divide defensive approaches to be either overarching or highly specific. In order to abstract away details for the purpose of tractability, overarching approaches can suffer because simplistic models for threats, vulnerabilities, and exploits tend to yield defenses that are too optimistic. Approaches that deal with specific threats, vulnerabilities and exploits may be more credible but can quickly lose their meaningfulness as technology changes. Whether approaches are near-or-far term, we see that two underlying attributes remain essential: the ability to survive and the ability to fight through.

The compendium of survival and fight through has, for us, spurred the need for this topic on survivability in cyberspace. Our justification for treating survival and fight-through as inseparable is: although cyberspace's apparent vastness seems to convey a limitless supply of information and network-related resources, the actual amount of these resources under any single genuine entity's control is typically very limited. However, an attacker's aim to overtake resources may not be easily bounded. Thus, driving our goal's dual survive-and-fight-through make-up is that while the part of cyberspace under single, genuine control is limited, for that same part of cyberspace an adversary's aim is to maximize control. This dictates that survive and fight-through remain joined. Considered separately, accumulated loss of resources to the adversary will eventually undermine the ability to survive or the ability to fight through – but that is not so for both. That is, surviving an attack by sustaining its damage and fighting through that attack - again and again if necessary - with those remaining resources under the defender's control allow the system to emerge, and remain, undefeated.

This topic is aimed at covering the breadth of survivability of cyberspace as outline above. Ideas that deal with solving some portion of the overall cyberspace survivability goal are welcome. A potential approach is to transform concepts from the field of fault tolerance to cyberspace survivability. Visiting faculty will perform in-house research as part of the Cyber Science branch's in-house research effort "Fault Tolerance for Fight Through".

Information Theoretic Secure Cloud Computing and Cloud Auditing

Keesook Han

Cloud computing represents one of the most significant shifts in information technology. However, there are persistent concerns about cloud computing security risks. This research aims to develop secure cloud computing and cloud auditing technologies in order to reduce cloud security vulnerabilities and increase the performance of cloud computing in hostile network

environment. Areas of interest include information theoretic security/secure computing applications, automatic cloud auditing, secure data management and sharing, efficient metadata management, compression, massive real-time stream data analysis and transmission, Quality of Service mechanism, router-based traffic control, access control, visualization, cyber threats analysis, and other cloud security applications including Android Smartphone security.

Market-Based and Game Theoretic Methods for Resource Allocation in the Cloud

Kevin Kwiat

Elizabeth Bentley

Information systems are continually expanding as evidenced by the doubling of Internet connections every year. Similar growth is exhibited by information systems in defense. The Air Force's mission to fly and fight in Air, Space, and Cyberspace involve the technologies to provide information to the warrior anywhere, anytime, and for any mission. This far-reaching enterprise will necessarily span multiple networks and computing domains that include those that are commercial and exclusively military. As a result, many users with different goals and priorities vie for the communication and computing resources. Managing this vast system to ensure dependable operation that maintains users' quality of service levels has led researchers to propose computational markets as a means for controlling the allocation of system resources. Economics has always been a factor in engineering. Because it is also the study of resource allocation problems, economics is sought to provide the answer to managing large-scale information systems. By introducing software agents, pricing mechanisms, and game-theoretic mechanisms, the computational economy will strive to exhibit the same phenomena as a real one; it will admit arbitrary scale, heterogeneity of resources, decentralized asynchronous operation, and tolerance of localized failures. These derived benefits are compelling and recent advances in cloud computing have created opportunities for the serious contemplation of building computational markets.

Application of Game Theory and Mechanism Design to Cyber Security

Charles Kamhoua

Cyber attacks pose a significant danger to our economic prosperity and national security whereas cyber security seeks to solidify a scientific basis. Cyber security is a challenging problem because of the interconnection of heterogeneous systems and the scale and complexity of cyberspace. This research opportunity is interested in theoretical models that can broaden the scientific foundations of cyber security and develop automated algorithms for making optimum decisions relevant to cyber security. Current approaches to cyber security that overly rely on heuristics have been demonstrated to have only limited success. Theoretical constructs or mathematical abstractions provide a rigorous scientific basis for cyber security because they allow for reasoning quantitatively about cyber attacks.

Cyber security can mathematically be modeled as a conflict between two types of agents: the attackers and the defenders. An attacker attempts to breach the system's security while the defenders protect the system. In this strategic interaction, each agent's action affects the goals and behaviors of others. Game theory provides a rich mathematical tool to analyze conflict in strategic interaction and thereby gain a deep understanding of cyber security issues. The Nash equilibrium analysis of the security games allows the defender to allocate cyber security resources, understand how to prioritize cyber defense activities, evaluate the potential security risks, and reliably predict the attacker's behavior.

Securing cyberspace needs innovative game theoretic models that consider practical scenarios such as: incomplete information, imperfect information, repeated interaction and imperfect monitoring. Moreover, additional challenges such as node mobility, situation awareness, and computational complexity are critical to the success of wireless network security. Furthermore, for making decisions on security investments, special attention should be given to the accurate value-added quantification of network security. New computing paradigms, such as cloud computing, should also be investigated for security investments.

We also explore novel security protocols that are developed using a mechanism design principle. Mechanism design can be applied to cyber security by designing strategy-proof security protocols or developing systems that are resilient to cyber attacks. A network defender can use mechanism design to implement security policies or rules that channel the attackers toward behaviors that are defensible (*i.e.*, the desired equilibrium for the defender).

Cyber Security Research and Applications

Charles Kamhoua

Securing cyberspace continues to be an active research area. Despite much progress, critically-important cybersecurity challenges remain. This is made evident by the many critical systems that have become exposed to new threats from vulnerabilities that malicious agents exploit. The resultant cyber-attacks have meant significant cost to private industries and government agencies. As a first step towards achieving the long-term and affordable goal of securing cyberspace, this research opportunity is interested in novel approaches to tackle a wide range of cyber security problems related to the following:

- Cyber-threat information sharing
- Cyber-threat monitoring
- Mathematical approaches to hardware Trojan detection
- Side channel attack in cloud computing
- Security of online social networks

Processing and Exploitation

Motion Imagery (or Video) Processing and Exploitation

Todd Howlett

Motion Imagery sources include everything from airborne collectors to YouTube. New and innovative technology is required to exploit and extract the relevant information content and manage the whole exploitation process. Visual processing is the focus, but leveraging all aspects of the data is of interest (e.g. audio and metadata) as well as using any additional correlating sources (e.g. reference imagery or coincident sensors). Both semi-automated and fully automated capabilities are of interest. Emphasis will be on overcoming or working around the current limit of computer vision to lead to a useful capability for an AF analyst. Sample topics of interest would be: biologically inspired techniques, scene classification, event detection, object detection and recognition, optimization techniques, Bayesian methods, geo-registration, indexing, etc.

Audio Processing

Stanley Wenndt

The Audio Group in AFRL/RIGC is involved in all aspect of speech processing and is a unique combination of linguists, mathematicians, DSP engineers, software engineers, and intelligence operators. This combination of individuals allows us to tackle a wide spectrum of topics from basic research such as channel estimation, robust word recognition, language and dialect identification, and confidence measures to the challenging transitional aspects of real-time implementation, GUI design, and concepts of operations. The Audio Group also has significant thrusts in noise estimation and removal, speaker identification including open-set identification, keyword spotting, robust feature extraction, language translation, analysis of stressed speech, coding algorithms along with the consequences of the compressions schemes, watermarking, co-channel mitigation, and recognition of background events in audio recordings.

Communications Processing Techniques

Doug Smith

We view communications processing as the gathering and exploitation of technical information derived from communication signals. The communication processing we perform mainly deals with the exploitation of messages or voice information but excludes open radio and television broadcasts. To perform exploitation, we need to develop advanced technologies to intercept, collect, locate and process communication signals in all parts of the spectrum. The objective is to maximize the information that can be extracted from this raw data. This information includes:

- Person or source of the communication
- Location of the transmitter
- Function of the transmitter
- Radio Frequency (RF) and other technical characteristics of the transmission
- Content of the transmission
- The recipient of the transmission

The end result is the development of automated processes to extract, analyze, correlate, sort and report information.

The technical challenges include: development of interference cancellation techniques/ multi-user detection (MUD) algorithms, beamforming techniques, hardware architecture and software methodologies, geolocation techniques and systems, and signal processing software. Research into developing unique and advanced methods to collect, process and exploit communication signals in high density rapidly changing environment is of great importance. The research is expected to be a combination of analytical and experimental analyses. Experimental aspects will be performed via simulations using an appropriate signal processing software tool, such as MATLAB.

Wireless Sensor Networks in Contested Environments

Lauren Huie-Seversky

Sensor networks are particularly versatile for a wide variety of detection and estimation tasks. Due to the nature of communication in a shared wireless medium, these sensors must operate in the presence of other co-located networks which may have competing, conflicting, and even adversarial objectives. This effort focuses on the development of the fundamental mathematics necessary to analyze the behavior of networks in contested environments. Security, fault tolerance, and methods for handling corrupted data in dynamically changing networks are of interest.

Research areas include but are not limited to optimization theory, information theory, detection/estimation theory, quickest detection, and game theory.

Development of new cryptographic techniques is not of interest under this research opportunity.

Advanced Object & Activity, Detection and Exploitation in Visual Imagery & Video Sources

Mark Alford

A summer faculty researcher is needed to explore new methods of image/video exploitation in large volumes of images and video data. The goal is to characterize events, entities, activities and scenarios in image data containing people (insurgents, for example), vehicles (suspicious),

and weapons (Rocket Propelled Grenades – RPGs) and other weaponry, such as those being employed by ISIS rebels immersed in terrain, people, ~~or among~~ buildings and other objects in general. These images can be readily found on the internet. The ultimate objective is to develop procedures that will go through several images and find all the ones that have a given attribute within them (for example, all these images contain RPGs). Methodologies must be developed in order to automatically determine the contents of the video. First algorithms to recognize objects and associate metadata to those objects are necessary in developing an understanding of imagery contents. Next, by summarizing the detailed characteristics of images and identifying kinematic patterns of those objects, one can develop a context behind object detection and tracking in a video. Further characterization of the objects can be added by querying databases for more detailed descriptions of the objects in the video. The focus will be on the actual video analysis, to assist the human in analyzing the video for patterns of life and normalcy pattern analysis. In addition to object recognition, there is a need to automate scene recognition and understanding. Possible areas of concentration include but are not limited to:

- Ground Truthing of image characteristics
- Discriminative scene understanding (with and without training)
- Space-time scene classification
- Scene categorization
- Annotation, segmentation of images

Big Data Analytics for Activity Based Intelligence

Douglas Boulware

AFRL seeks innovative research in the area Big Data Analytics for Activity Based Intelligence (ABI). More specifically, AFRL seeks automated or semi-automated procedures to characterize and locate activities and actions/transactions, identify and locate actors and entities conducting the activities and transactions, determine the existence, topology, leadership, and other characteristics of covert networks, understand the relationships between networks, and determine patterns of life from large amounts of externally observed data. Research interests also include the discovery and understanding of unknown activities and associated trends/patterns/relationships. In addition, these techniques should move beyond the limitations of traditional approaches to consider temporal dynamics and\or multi-modal networks and are most interesting when researched in the context of a variety intelligence sources and types and the challenges presented by “Big Data.”

Foundations of Resilient and Trusted Systems

Steven Drager

Research opportunities are available for the model-based design, development and demonstration of foundations of resilient and trustworthy computing, including technology,

components and methods supporting a wide range of requirements for improving the resiliency and trustworthiness of computing systems via multiple resilience and trust anchors throughout the system life cycle. Research supports security, resiliency, reliability, privacy and usability leading to high levels of availability, dependability, confidentiality and manageability. Thrusts include hardware, middleware and software theories, methodologies, techniques and tools for resilient and trusted, correct-by-construction, composable software and system development. Specific areas of interest include: perpetual model validation (both of the system interacting with the environment and the model itself), trusted resiliency and evolvability; reduced complexity of autonomous systems; effective resilient and trusted real-time multi-core exploitation; architectural security, resiliency and trust; provably correct complex software and systems; composability and predictability of complex real-time systems; resiliency and trustworthiness of open source software; scalable formal methods for verification and validation to prove trust in complex systems; novel methodologies and techniques which overcome the expense of current evidence generation/collection techniques for certification and accreditation; and a calculus of resilience and trust allowing resilient and trusted systems to be composed from untrusted components.

High Assurance Computing

Wilmar Sifre

The objective of this topic is to investigate the necessary building blocks for high assurance computing environments (environments where compelling evidence is supplied to determine a high level of trustworthiness), including both the underlying hardware and software to support it. Areas of interest include, but are not limited to: (1) the problems and challenges with current processor designs for trustworthiness and their solutions; (2) the problems and challenges with current computer architectures for trustworthiness and solutions to them; (3) the Operating System level constructs, objects, and functions that must be provided to complement the hardware to enable a trustworthy computing base; (4) state of the art software-based assurance designs, methodologies or concepts which are better suited for implementation in hardware than software; (5) research and development for increasing the level of trustworthiness of integrated circuit designs, commodity integrated circuits and currently available systems as a whole; (6) research into and development of solutions to mitigate implications of state-of-the-art commercially available processor architectures (including multi-core, GPUs, FPGAs, etc.) and specially designed processor architectures on Separation Kernels and other secure micro-kernels being developed by real-time operating system vendors for use in environments requiring high assurances; and (7) research and development supporting software, e.g. high assurance middleware technologies, to enhance system interoperability and capability to support cross domain solutions enabling delivery of trustworthy, superior and timely information.

Formal Methods for Complex Systems

Dilia Rodriguez

Formal methods are based on areas of mathematics that support reasoning about systems. They have been successful in supporting the design and analysis of systems of moderate complexity. Today's formal methods, however, cannot address the complexity of the computing infrastructure needed for our defense.

This area supports investigation on new powerful formal methods covering a range of activities throughout the lifecycle of a system: specification, design, modeling, and evolution. New mathematical notions are needed: to address the state-explosion problem, new powerful forms of abstraction, and composition. Furthermore, novel semantically sound integration of formal methods is also of interest. The goal is to develop tools that are based on rigorous mathematical notions, and provide useful, powerful, formal support in the development and evolution of complex systems.

Trusted Software-Intensive Systems Engineering

William McKeever

Software is a prime enabler of complex weapons systems and its fungible nature is key to the development of next generation adaptive systems.

Yet, software is the most problematic element of large scale systems, dominated by unmet requirements and leading to cost and schedule overruns. As the complexity of today's system lies in greater than 10^5 requirements, greater than 10^7 lines of code, thousands of component interactions, greater than 30 year product life cycles and stringent certification standards. The tools used to design, develop and test these complex systems do little to instill trust that the software is free from vulnerabilities, malicious code or that it will function correctly. Furthermore there is virtually no tool capable of detecting design flaws or vulnerabilities in an algorithm. The objective of the trusted software-intensive systems engineering topic is to develop techniques and tools to enable trust (with a focus on security and correctness) throughout the software lifecycle.

Areas of interest include: evidence-based software assurance; static analysis tools with a preference to analysis at the binary level; algorithm or design-level analysis; secure software development; model-based software engineering; correct-by-construction software generation;

Many-Node Computing for Cognitive Operations

Thomas Renz

The sea change in computing hardware architectures, away from faster cycle rates and towards processor parallelism, has expanded opportunities for development of large scale physical architectures that are optimized for specific operations. Porting of current cognitive computing

paradigms onto systems composed of parallel mainstream processors will continue in the commercial world. What higher cognitive functionality could we achieve if we take better advantage of physical capabilities enabled by new multi-processor geometries?

Perception, object recognition and assignment to semantic categories are examples of lower level cognitive functions. Assignment of valence, creation of goals and planning are mid level functions. Self awareness and reflection are higher level processes that are so far beyond current cognitive systems that relatively little has been done to model the processes. Often, models assume higher cognitive processes will emerge, once the computing system reaches some level of speed / complexity. The problem is that the computational power required exceeded the reachable limit of single processor architectures and probably exceeds the limits of conventional parallel architectures. This topic seeks to enable mid and higher level cognitive function by creation of new physical architectures that address the computation demand in novel ways.

We are interested in developing models for the computational scale of the mid and higher functions and processor / memory node architectures that facilitate cognitive operations by configuring the physical architecture to closely resemble the functional cognitive architecture, e.g., where each node in a network represents and functions as a processor for a single semantic primitive. What new hierarchical architectures could we design for million node systems, where the individual nodes may be small ASPs, with very fast communication between nodes? A project of interest would combine both sides, new algorithms for higher level cognitive functions and new architectures to enable the computation in a realistic time frame. AFRL/RIT has projects on line to enable million node systems.

Nanocomputing

Joseph Van Nostrand

Advances in nanoscience and technology show great promise in the bottom-up development of smaller, faster, and reduced power computing systems. Nanotechnology research in this group is focused on the development of crossbar computing architectures which utilize existing nanotechnologies including nanowires, coated nanoshells, memristors, and carbon nanotubes and are scalable to 100x100 arrays. We have a particular interest in the modeling and simulation of architectures that exploit the unique properties of these new and novel nanotechnologies. This includes development of nonlinear sub-circuit models that accurately represent sub-circuit performance with subsequent CMOS integration. Also of interest are the use of nanoelectronics and thermal management techniques using nanotechnologies in 3D computer architectures.

Quantum Computing Theory and Simulation

Paul Alsing

Quantum computing research involves interdisciplinary theoretical and experimental work from diverse fields such as physics, electrical and computer science, engineering and from pure and applied mathematics. Objectives of AFRL's Emerging Computing Technology Branch include

the development of quantum algorithms with an emphasis on large scale scientific computing and search/decision applications/optimization, implementations of quantum computational schemes with low error threshold rates, implementations of quantum error correction such as topological protection, and the simulation of quantum circuits/computers and quantum error correction schemes with an emphasis on modeling experiments. Topics of special interest include the cluster state quantum computing paradigm, quantum simulated annealing, the behavior of quantum information and entanglement under arbitrary motion of qubits, measures of quantum entanglement, and the distinction between quantum and classical information and its subsequent exploitation.

Compressive Sampling

Bruce Suter

As the size shrinks for future small autonomous UAVs, they will increasingly find it more and more difficult to support high capacity data links and large on-board processing requirements for data-heavy sensing applications. One approach to solving this problem is to develop compressive sampling architectures and algorithms which will reduce the communications bandwidth, while allowing simple encoding and adaptive decoding. This topic addresses the theory and applications of compressive sampling. This includes:

- Development of a theoretical framework for compressive sampling. Some promising directions are based in part on the study of multilevel and nonconvex optimization.
- Application of computational methods to advance the state-of-the-art in airborne networking. For example, the realization of rank deficient network coding as an application of compressive sampling.
- Application of compressive sampling to permit novel computational paradigms. Such paradigms show potential for a myriad of applications, including wireless parallel computers

Quantum Information Processing

Michael Fanto

The topic of Quantum Information Processing is to be focused on Computational Methods and Architectures. It has been well established that a computer based on quantum interference could offer significant increases in processing efficiency and speed over classical versions, and specific algorithms have been developed to demonstrate this in tasks of high potential interest such as data base searches, pattern recognition, and unconstrained optimization.

However the present experimental progress, lagging far behind the theoretical, is at the level of several gates or Q bits. The entangled photon approach to quantum gates including quantum gates, cluster states, and Linear Optical Quantum Computing will be experimentally pursued with particular attention to scalability issues. Experience with generation and detection of entangled photons is essential for this interaction, with parametric amplification a plus.

Theoretical advances will also be pursued with existing and custom quantum simulation software to model computational speedup, error correction and de-coherence effects. Algorithm investigation will focus on hybrid approaches which simplify the physical realization constraints and specifically address tasks of potential military interest.

Optical Interconnects

Joseph Osman

AFRL's Emerging Computing Technologies Branch offers research opportunities in the area of computer optical interconnects closely coupled in effective ways to processors and/or memories in order to decrease the latency associated with standard interconnects and intra-computer communication. Novel optical interconnect components, architectures, algorithms and subsystems are needed to perform inter-processor, processor to memory and memory to memory interconnects. This includes through open space for compact multiprocessor cores or through optical fibers and/or waveguide for processor to processor interconnects in computational clusters.

Our main area of interest is the design, modeling, and building of interconnect devices for advance high performance computing architectures with an emphasis on interconnects for quantum computing and the use of plasmonic techniques. Current research focuses on interconnects for quantum computing including switching of entangled photons for time-bin entanglement. With its ability to supply a very high field in a very small area, plasmonics is a very promising technique in the quest to make nanoscale optical interconnects components.

Quantum computing is currently searching for a way to make meaningful progress without requiring a single computer with a very large number of qubits. The idea of quantum cluster computing, which consists of interconnected modules each consisting of a more manageable smaller number of qubits is attractive for this reason. The qubits and quantum memory may be fashioned using dissimilar technologies and interconnecting such clusters will require pioneering work in the area of quantum interconnects. The communication abilities of optics as well as the ability of optics to determine the current state of many material systems makes optics a prime candidate for these quantum interconnects.

Neuromorphic Computing

Clare Thiem

Neuromorphic computing shows great promise in the development of intelligent systems able to imitate natural neuro-biological processes such as reasoning and perception. This is achieved by artificially recreating the highly parallelized computing architecture of the mammalian brain. In particular, neuromorphic computers are suitable for applications in pattern recognition and optimization, i.e. target finding, automated data processing, intelligence analysis, etc. In order to achieve high levels of intelligence within systems, neuromorphic computing exploits the characteristic behavior of novel complex materials and structures with advanced processing

techniques to achieve very large scale integration with highly parallel neural architectures. This research effort will focus on mathematical models, computing architectures and computational applications to develop neuromorphic computing processors. Also of interest, is the development of neuromorphic computing architecture software emulation and hybrid VLSI CMOS architectures utilizing nano- scale technologies. Special emphasis will be placed on promising technologies and solutions to satisfy future Air Force needs employing intelligent systems to achieve the desired level of autonomy.

Advanced Computing Processors Information Management

George Ramseyer

As the number of computing processors is increased for most applications, a situation is reached where processor information management becomes the bottleneck in scaling, and adding additional processors beyond these number results in a deleterious increase in processing time. Some examples that limit scalability include bus and switch contentions, memory contentions, and cache misses, all of which increase disproportionally as the number of processors increase. The objective of this topic is to investigate existing and/or to develop novel methods of processor information management for multiprocessor and many-processor computing architectures that will allow for increased scaling.

Large Scale Geometric Reasoning & Modeling

Lee Seversky

This research effort focuses on developing the mathematical tools and algorithms necessary for the efficient management, processing, and analysis of very large geometric data collections. Example datasets of interest include aerial and terrestrial range data, unstructured image collections, and high-resolution video. Special consideration will be given to topics that propose novel ways for exploiting massive datasets for the efficient storage, representation, retrieval, and exploration of the information captured by the data which would not otherwise be possible in the small scale. Specifically, it is of interest to explore and develop new ways for obtaining and best utilizing human weak supervision to support tasks such as scene reconstruction, segmentation, object recognition, classification, localization, and learning multi-attribute similarity and ranking functions on the large scale in a collaborative setting. The applicant should have a strong research record in related areas such as geometry processing, computer vision, computer graphics, machine learning, and applied mathematics.

Complex Network and Information Modeling & Inference

Lee Seversky

Lauren Huie-Seversky

Matthew Berger

Recent advances in sensing technology have enabled the capture of dynamic heterogeneous network and information system data. However, due to limited resources it is not practical to measure a complete snapshot of the network or system at any given time. This topic is focused on inferring the full system or a close approximation from a minimal set of measurements. Relevant areas of interest include matrix completion, low-rank modeling, online subspace tracking, classification, clustering, and ranking of single and multi-modal data, all in the context of active learning and sampling of very large and dynamic systems. Applications areas of interest include, but are not limited to communication, social, and computational network analysis, system monitoring, anomaly detection, video processing. Also of interest are topological methods such as robust geometric inference, statistical topological data analysis, and computational homology and persistence. The exploration of new techniques and efficient algorithms for topological data analysis of time-varying and dynamic systems is of particular interest. Candidates should have a strong research record in these areas.

Event Detection and Predictive Assessment in Near-real Time Complex Systems

Misty Blowers

Making best use of multi-point observations and sensor information for event detection and predictive assessment in complex, near real time systems is a challenge which presents itself in many military domains. The first step in tackling these challenges is to analyze and understand the data. Depending on the algorithm used to detect an anomalous event, the nature and extent of variable correlations must be understood. This research will consider methods to quantify the strength of the correlations of input variables to output variables and develop techniques to account for lag times in the data itself. This is no easy task since sensor readings and operator logs are sometimes inconsistent and/or unreliable, some catastrophic failures can be almost impossible to predict, and time lags and leads in real world systems may vary from one day to the next. After detecting where the strongest correlations exist, one must choose a model which can best assess the current conditions and then predict the possible outcomes that could occur for a number of possible scenarios. Scientific issues of interest include, but are not limited to (1) advanced statistical methods to determine dependencies between senor inputs and the combined effect of multiple-sensors (2) adaptive correlation analysis techniques which will evolve to discover new dependencies in time as conditions change (3) adaptive pattern matching methods to take correlated sensor inputs and characterize normalcy and anomalous conditions.

Interleaving Acquisition and Processing of Geometric Data

Matthew Berger

3D geometric data is becoming highly pervasive, both in terms of the acquisition and the analysis of such data. In constrained environments, however, the resources available for acquisition are limited. Moreover, the resulting geometry may be highly imperfect in terms of noise and completeness, necessitating new techniques for analysis.

This research effort focuses on new techniques for the acquisition of 3D geometric data under limited resources, and the analysis of such data. Of particular interest is the interleaving of acquisition and analysis, where an understanding of the environment drives the acquisition process. Topics for geometry acquisition include, but are not limited to: multi-view stereo, photometric stereo, structured lighting, shape from image collections, surround methods for full environment acquisition, as well as the potential fusion of these and other modalities. Topics for geometry processing include, but are not limited to: surface reconstruction, registration, segmentation, scene summarization, large scale and out-of-core management of geometric data, as well as data-driven analysis of geometry. Applicants should have a strong background in geometry processing, computer vision, machine learning, and applied mathematics

Information Fusion Performance Evaluation

Erik Blasch

Information Fusion (IF) is a research area that seeks to reduce uncertainty, extend sensing and situation awareness, and refine estimates based on data, feature, and decision association and correlation. IF has been applied to many domains; but still requires methods of comparative analysis, unique situations for multi-INT coordination, and novel mathematics in algorithm development for complex systems that integrate sensing and user interaction for timely processing and exploitation. Our challenge is to develop the necessary insights and identify the best practices to help foster and accelerate scientific discovery vital for developing affordable IF systems with predictable measures of performance for sensor resource management. A candidate set of problems includes and is not limited to the following list: 1) challenging IF problems in wide area persistent surveillance; activity analysis in complex multi-dimensional spatio-temporal data-sets, and tactical sensing situations; 2) advanced scientific image and textual analysis and knowledge discovery techniques on scalable large data sources; 3) methods of physics-based and human-based sensor fusion using multiscale (e.g. signal processing, machine-learning, and information management) algorithms in the context of anticipative computing; 4) design of experiments for performance analysis over practical and explorative scientific studies; and, 5) any topic of relevance to Air Force mission involving application science, large scale computing, precision and performance metrics driven operational (e.g. sensor, target, and environment) constraints.

Fusion of Physics-Derived and Human-Derived Data

Erik Blasch

Techniques for physics-derived applications are prevalent such as simultaneous tracking and classification/identification and sensor exploitation. Likewise, efforts from natural language processing have enabled text extraction. Currently, there is a need to combine various intelligent data sources towards a combined physics-based and human-derived information fusion solution. The technical challenge is to understand and model the association between these sources of information, combined with the algorithms that extract and exploit information towards a robust solution. The performance evaluation of these efforts require understanding of the data, metrics, and usefulness of how, when, and where to best combine the methods. We are interested in the theoretical and practical problems over scenarios that provide situation assessment, awareness and understanding over different sensors, targets, and environments. The scope of the inputs include: video, text, voice, and scanned archives for air, space, and cyber activities. Developments for situation awareness (e.g., The Data Fusion Information Group Model of Level 2 Fusion "Situation Assessment"), include entity, event, and group behavior modeling, measurement, and performance analysis from which novel solutions are sought.

Enhanced Exploitation and Analysis Tools

Erik Blasch

Research in data, sensor, and information fusion supports numerous applications; however, the ability of techniques and tools to support operational needs is based on user attributes (e.g., The Data Fusion Information Group Model of Level 5 Fusion "User Refinement"). A current need is to understand how different tools such as target trackers, semantic extraction engines, and data exploitation methods support users. Research questions include advanced computing, analytics, security, data visualization, and human-machine interaction. Various applications such as full motion video (FMV), hyperspectral imaging (HSI), high-range resolution radar (HRR), satellite imagery, wide area motion imagery (WAMI), text, and Open Source Intelligence (OSINT) require different techniques to balance user interaction and machine exploitation. The technical challenge is to achieve a robust balance between computational effort, timeliness, and performance between databases, users and exploitation tools. We are interested in the academic and application problems that bridge the balance for unstructured scene perception, semantic understanding, and data control over multiple spatial, temporal, and frequency scales. The detection, characterization, and learning of patterns that impact exploitation, tracking, prediction, and validation of potential targets for activity-based intelligence will be of interest. Various analytical and practical tools that capture autonomous decision making, build assistive tools, and facilitate reporting will be considered.

Programming for Emerging Nonlinear Computer Architectures

Lok Yan

Modern computer architectures are separated into multiple abstraction layers: hardware, firmware, operating system, middleware, applications, etc. In this organization, low level details are abstracted away from higher level users. For instance, application programmers can focus on designing and implementing new algorithms and functionality without having to worry about the intimate details of instruction set architectures, physical memory management, communications protocols, etc. While this organization has been great for implementing everyday applications, the abstraction layers have actually been a hindrance for specialized applications. In order to attain high algorithmic efficiency, scientific computing practitioners must understand the details of available instruction sets (e.g., MMX and SSE), pipelining, cache design and memory bus bandwidth, amongst others. Similarly, security implementers must be cognizant of any special hardware (e.g., TPM chips and AES-NI extensions) to attain high performance and security. The same applies to nonlinear computing as well. In other words, the abstraction layers do not exist for these specialized applications and neither do their benefits.

However, as performance and security have become mainstream problems, new middleware and programming paradigms have been introduced. For example CUDA and OpenCL are two new programming paradigms that help abstract away some of the details of stream programming. Users write code in a C like language, and the compiler takes care of data organization and stream processor allocation. Hadoop is another example of a middleware that abstracts away the details of parallel and distributed programming and exposes the much simplified map-reduce algorithm.

This topic seeks to research and develop techniques and tools for abstracting away the details of a nonlinear computing system. An example topic of interest is compilers or middleware that abstract away the dynamic nature of chaos computers. In this way, if chaos computing is used for code obfuscation, the compiler is, in essence, a program obfuscator. A second example is model based design and implementation for nonlinear computing components. In this example topic, the different nonlinear computing instantiations are formally modeled. These models are then used to compose applications and runtime code that abide by user specifications.

Towards Precise Low Level Program Analysis

Lok Yan

Program analysis has traditionally been separated into two categories – dynamic and static. In dynamic analysis the sample under test is executed and its runtime behavior is analyzed. In static analysis, the sample is analyzed at rest. The main benefit of static analysis is code coverage, (e.g., the full control flow graph of a sample can be built) however, its main disadvantage is the lack of runtime or concrete data values. Conversely, the advantage of dynamic analysis is the availability of concrete information and the disadvantage is the lack of coverage. Thus, program analysis in practice is likely to use both static and dynamic techniques.

There are also different dimensions to program analysis. Analysis-granularity is one of them. For obvious reasons, analyzing a program at a high level representation (e.g., source code) can benefit from the available contextual information which is lost when a program is analyzed at a lower level (e.g., assembly). This loss of high level information, in turn, leads to a loss of precision (i.e., increase in false positives). Unfortunately, low level analysis is the only viable approach for many applications. For instance, malware samples normally arrive as binaries and not as source code.

The main goal of this topic is to investigate techniques that can be used to increase the precision of low level analysis. To put it differently, how can we make low level analysis as precise possible with the upper bound being high level analysis? The proposed work should initially focus on individual sub problems in program analysis – information flow, control dependency, etc.

Secure Processing Systems

John Rooks

The objective of the Secure Processing Systems topic is to develop hardware that supports maintaining control of our computing systems. Currently most commercial computing systems are built with the requirement to quickly and easily pick up new functionality. This also leaves the systems very vulnerable to picking up unwanted functionality. By adding specific features to microprocessors and limiting the software initially installed on the system we can obtain the needed functionality yet not be vulnerable to attacks which push new code to our system. Many of these techniques are known however there is little commercial demand for products that are difficult and time consuming to reprogram no matter how much security they provided. As a result the focus of this topic is selecting techniques and demonstrating them through the fabrication of a secure processor. Areas of interest include: 1) design, layout, timing and noise analysis of digital integrated circuits, 2) Implementing a trusted processor design and verifying that design, 3) Selection of security features for a microprocessor design, 4) verifying manufactured parts, and 5) demonstrations of the resulting hardware.

Edge of Chaos Computational Architectures and Cortical Networks

Bryant Wysocki

Recent advancements in nanoelectronics, photonics, neuromorphic systems, and cognitive neuroscience are enabling the development of radically different computational architectures based on reservoir computing concepts. Such systems are theoretically capable of solving the toughest temporal/spatial classification and regression problems with Air Force applications focused on increased system autonomy and perception. This research explores a new class of computationally intelligent processers governed by the nonlinear dynamics within oscillating optical or electronic reservoirs. The nonlinear dynamics and delayed feedback (short term memory) of reservoirs enable networks to mimic transient neuronal responses and to project time dependent input into high dimensionalities for categorization by an outside classifier. Such hardware based reservoirs can operate near the edge of chaos providing extreme sensitivity to input variations for increased degrees of separability between input signatures. In this context, the reservoirs function as time delayed recursive networks that utilize feedback as short term dynamic memory for the processing of time-series input signals. These systems offer potentially disruptive capabilities in real time signature analysis, time-series predictions, and environmental perception for autonomous operations. Interests associated with this topic include; exploration of the required properties and associated mechanisms to build efficient reservoirs, system modeling, spike-timing-dependent plasticity (STDP), and cortical architectures, with emphasis on bio-inspired computational schemes based on the physics of near chaotic systems.

Mathematical Theory for Advances in Machine Learning and Pattern Recognition

Ashley Prater

To alleviate the effects of the so-called ‘curse of dimensionality’, researcher have developed sparse, hierarchical and distributed computing techniques to allow timely and meaningful extraction of intelligence from large amounts of data. As the amount of data available to analysts continues to grow, a strong mathematical foundation for new techniques is required. This research topic is focused on the development of theoretical mathematics with applications to machine learning and pattern recognition with a special emphasis on techniques that admit sparse, hierarchical or parallelizable numerical methods. Research may be performed in, but not limited to: sparse PCA, generalized Fourier series, low-rank matrix approximation and compressed sensing. Proposals with a strong mathematical foundation will receive special consideration.

Formal Verification and Analysis of Hybrid Cyber-Physical Systems

Stanley Bak

Next-generation cyber-physical systems consist of both discrete components (software) interacting with analog components (the physical world). For this reason, verification and

analysis of these hybrid systems is of particular interest. However, many challenges remain in the area of formal reasoning of these types of systems.

This topic aims to advance basic research in the formal analysis of hybrid systems, particularly the analysis of hybrid automata. Specifically, fundamental advancements in reachability analysis, synthesis, automated abstraction, improved scalability, and practical case studies are of interest.

Dynamical Reservoir Computing

Bryant Wysocki

Recent advancements in nanoelectronics, photonics, neuromorphic systems, and cognitive neuroscience are enabling the development of radically different computational architectures based on reservoir computing concepts. Such systems are theoretically capable of solving the toughest temporal/spatial classification and regression problems with Air Force applications focused on increased system autonomy and perception. This research explores a new class of computationally intelligent processers governed by the nonlinear dynamics within oscillating optical or electronic reservoirs. The nonlinear dynamics and delayed feedback (short term memory) of reservoirs enable networks to mimic transient neuronal responses and to project time dependent input into high dimensionalities for categorization by an outside classifier. Such hardware based reservoirs can operate near the edge of chaos providing extreme sensitivity to input variations for increased degrees of separability between input signatures. In this context, the reservoirs function as time delayed recursive networks that utilize feedback as short term dynamic memory for the processing of time-series input signals. These systems offer potentially disruptive capabilities in real time signature analysis, time-series predictions, and environmental perception for autonomous operations. Interests associated with this topic include; exploration of the required properties and associated mechanisms to build efficient reservoirs, system modeling, spike-timing-dependent plasticity (STDP), memristive systems, and cortical architectures, with emphasis on bio-inspired computational schemes based on the physics of nonlinear systems.

Quantum Networking with Atom-based Quantum Repeaters

Kathy-Anne Soderberg

A key step towards realizing a quantum network is the demonstration of long distance quantum communication. Thus far, using photons for long distance communication has proven challenging due to the absorption and other losses encountered when transmitting photons through optical fibers over long distances. An alternative, promising approach is to use atom-based quantum repeaters combined with purification/distillation techniques to transmit information over longer distances. This in-house research program will focus on trapped-ion based quantum repeaters featuring small arrays of trapped-ion qubits connected through photonic qubits. These techniques can be used to either transmit information between a single beginning and end point, or extended to create small networks with many users.

Advanced High Speed Data Links

Yassir Salama

This in-house research effort focuses on very high speed data links (multi-gigabits) built on commercial standards such as IEEE std. 802.16 We are exploring the advantages of using orthogonal frequency division multiplexing and multi-access (OFDM, and OFDMA). In order to achieve multi-gigabit performance, we are investigating the use of ultra wide band communication scheme with high order modulation techniques. Several challenge topics need to be investigated in this project. These topics include, but not limited to:

- Doppler Frequency spread for ultra wide band communication systems using OFDM/OFDMA in high mobility airborne environment
- Peak-to-Average Power Ratio (PAPR) mitigation in OFDM communication system
- Clock and Carrier recovery techniques in very high speed communication systems
- Time and Frequency synchronization in OFDM/OFDMA communication systems
- Real-time high efficiency Forward Error Correction (FEC) techniques using state-of-the-art FPGA design

Advanced Event Detection and Specification in Streaming Video

Alex Aved

Video is leveraged for a variety of monitoring tasks, ranging from the monitoring of bridges, traffic and the interior of large buildings, to providing situational awareness in real time via unmanned aircraft. Current systems require human operators who must maintain high levels of constant vigilance monitor. The goal is to develop algorithms that operate in real time (or near real time) that can detect and characterize ~~both~~ short-term events (recognized in a single or few consecutive frames of video) and/or long-term activities (composed of one or more correlated events) that can occur in a timespan of seconds, minutes or hours. Also of interest are enabling technologies and techniques; to include but not limited to the specification of events via high level query languages, query optimization, multi-INT data fusion (e.g. to include combining multiple modalities of data into a stream amenable to off-line search and retrieval or subsequent processing in a cloud computing environment). Architectures of interest include both CPU and GPU, as well as cloud/distributed systems and mobile devices.

Knowledge Extraction from the Imbalanced Data Problem

Walter Bennette

To support the Air Force mission, the processing and exploitation of data is crucial. One challenging aspect of data exploitation is the extraction of interpretable and actionable knowledge through classification. This is particularly challenging when the interesting aspects of

a dataset are underrepresented. Current methods that aid in the interpretable classification of imbalanced data rely on techniques requiring advanced knowledge with unclear areas of applicability and mixed levels of success. This compounding problem can result in an analyst having low confidence in the extracted knowledge. We are seeking individuals with new and interesting ideas on how to help analysts with a rudimentary understanding of classification techniques have success in light of the imbalanced data problem. Interested topics include but are not limited to:

- Measures to evaluate the classification of imbalanced data
- Objective driven data sampling
- Interpretable classification techniques
- Data visualization for knowledge extraction and confidence building
- Ideas for minimal instruction to build competent data analysts including techniques to periodically evaluate and realign analysts' skills

Feature-Based Projection of Threats

Carolyn Sheaff

Methods have been developed to detect anomalous behaviors of adversaries as represented within sensor data, but autonomous projections of actual threats to US assets require further investigation and development. The proposed research will investigate and develop both the foundation and the algorithms that can predict the type of threat a red asset poses to a blue asset. The inputs to the system may include: 1) an indication/warning mechanism that indicates anomalous behavior exists, and 2) a classification of the type of red/blue asset. Approaches to consider include, but not limited to, projections based on offensive/defensive guidance templates and techniques associated with machine learning. The approach can be applied to any threat domain. The example that follows illustrates application to U.S. satellite protection. The offensive template determine the type of threat. The classification algorithm provides notification of the type of asset it is. The classification approach is employed to (for example) determine whether the asset is intact or a fragment, its control states, the type of control state, and whether it is a rocket body, payload, or debris. n example of an offensive assessment is a mass-inertia configuration change in an active red asset that is specific for robotic arm-type movements. Mechanisms such as templates are used to project whether or not this asset is a threat by comparing configuration changes with known threatening scenarios through probabilistic analyses, such as Bayesian inferences. Robustness tests may be employed as well. For example, a threat can be simulated that is not specific to one template. The question to be answered is: can a combination of the templates handle this case? The defensive portion must provide countermeasures, i.e. as in the case of a blue satellite, thruster burns to move away from possible threats.